Commentary: Object and Spatial Visualization in Geosciences

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ABSTRACT

Cognitive science research shows that the brain has two systems for processing visual information, one specialized for spatial information such as position, orientation, and trajectory, and the other specialized for information used to identify objects, such as color, shape and texture. Some individuals seem to be more facile with the spatial visualization system, while others favor the object visualization system. This commentary hypothesizes that geosciences draw heavily on *both* systems, in contrast to other studied professions whose practitioners tend to be strong at spatial visualization (e.g. physics), or object visualization (e.g. visual arts). Candidate object visualization tasks in geosciences include identifying rocks, minerals and fossils, and interpreting remote sensing images. Candidate spatial visualization tasks include envisioning the folding and faulting of sedimentary strata, and envisioning a 3-D volume from 2-D data. In general education, geoscience activities rich in object-visualization could provide an opportunity to motivate and empower a population—object visualizers—who may have disliked prior science courses. In the education of geoscience specializers, a challenge is to find instructional supports to strengthen the object visualization skills of spatial visualizers, and the spatial visualization skills of object visualizers, to produce graduates with both competencies.

INTRODUCTION

> *"If you dredged a rock sample from near the crest of a mid-ocean ridge, which rock type would you be most likely to recover? (a) basalt, (b) sandstone, (c) granite, (d) not enough information to tell."*

The question above looks like a routine and fairly mundane assessment item that might appear on a summative assessment in a high school or introductory college Earth Science course, drawing content from a unit on plate tectonics and a unit on igneous rocks. But now look at figure 1, which shows three variants of the same question. Version A, originally in color, requires the student to interpret shapes and colors to identify the locality in question as a mid-ocean spreading center, and to interpret colors and textures to identify the correct rock type by its appearances rather than its name. Version B requires the student to interpret the symbol set of an abstract spatial representation, a map, to identify the locality in question as a spreading center.

At a superficial, content-knowledge level, the three variants of figure 1 all test students' knowledge of the same basic factoid, derived from the same intro-level classroom, textbook, and laboratory instruction. Yet most geoscience instructors who have looked at these three items sense that they differ importantly from each other, and that the different forms of the question would advantage different students.

The goal of this commentary is to share with JGE readers the highlights of a intriguing body of cognitive science research that may form a useful framework for thinking methodically about the nature of geoscience tasks such as those in figure 1. The research concerns how humans process, encode, and store information obtained visually. Rather than being a monolithic ability, some researchers distinguish between "spatial visualization" and "object visualization," where the former enables humans to perceive and interpret information about position and orientation, while the latter enables us to perceive and interpret information about properties such as shape, color, and texture. Researchers who make this distinction have shown that some individuals and some professions tend to favor one or the other form of visualization. In this commentary, I hypothesize that geosciences draw heavily on *both* types of visualization. If so, there are important implications for how we educate and motivate both non-specialists and future geoscientists, as well as a rich vein of inquiry for geoscience education researchers.

The commentary begins with a brief foray into neurosciences to establish the evidence for the existence of two separate visual pathways in the brain, and then reviews claims that the existence of these separate visual pathways may manifest in individual differences in cognitive style, problem solving approach, and aptitude or propensity for certain professions. Published criteria for identifying spatial and object visualizers are then compared to selected geoscience tasks. The commentary concludes with implications for instructional design for both geoscience majors and the general public.

THE VIEW FROM INSIDE THE BRAIN: "WHAT" AND "WHERE" VISUAL PATHWAYS

Scientists who study the brain have found that the higher level visual areas of the human and primate brain are divided into two functionally and anatomically distinct pathways (e.g. Ungerleider and Haxby, 1994; Milner and Goodale, 1995). The retina converts light rays into nerve impulses, which traverse the optic nerve and reach the primary visual cortex at the rear of the brain. From there, visual information follows two pathways. The "dorsal pathway" traverses the back and top of the brain to the parietal cortex, while the "ventral pathway" travels deeper inside the brain to the temporal lobe. The dorsal pathway is involved in locating objects, and is thus also called the "where" pathway, or the "spatial pathway." This pathway processes properties that are critical for grasping and manipulating objects, such as their size, position, and orientation in space. The ventral visual pathway is involved in recognizing objects, and is thus sometimes called the "what pathway" or the "object pathway." This pathway processes information about

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intrinsic visual properties of objects, such as shape, color and texture. When a human reaches for a pencil on a cluttered desk, the ventral "what" pathway identifies the appropriate object amid the visually complex viewscape, while the dorsal "where" pathway guides movement of the grasping hand through space (example from Dubuc, n.d.).

Farah et al. (1988) showed that this dissociation between spatial information and information used for object recognition applies not only to those things that the person is actively seeing in real time, but also to mental imagery. Patients who have brain injuries in the "what pathway" region of their brain do poorly at drawing objects' appearance from memory, and at recognizing people, plants, animals or common objects--although they can draw maps and describe spatial layouts of scenes from memory. Conversely, patients who have brain injuries in the "where pathway" region of their brain do poorly at describing and drawing the spatial layout of scenes, but they can describe and draw objects from memory. When healthy subjects visualize a map they have memorized, their brains are activated in the region of the "where pathway," whereas when they visualize colors or faces there is activation in the "what pathway" region (Uhl et al., 1990).

"VERBALIZER," "SPATIAL VISUALIZER," AND "OBJECT VISUALIZER" COGNITIVE STYLES

"Cognitive style" refers to an individual's preferred mode of gathering, processing, remembering, and conveying information, and using information to solve problems. Historically (see review in Kozhevnikov et al., 2002), a distinction was drawn between verbal cognitive style and visual-spatial or visual cognitive style. However, when Hegarty and Kozhevnikov (1999) looked critically at what strategies individuals use to solve a math problem that could be solved either using either verbal or visual representations and methods, they found that there was there was not a single, coherent "visual" group. Rather, they found one group who used schematic representations, and a second group who used pictorial representations. Use of schematic diagrams was significantly correlated with high success on math problems, whereas use of pictorial diagrams was negatively correlated with math performance.

Kozhevnikov et al. (2002) carried this line of research into science education. When students who had not studied physics were asked to interpret a graph with time on the horizontal and position on the vertical axis, high-spatial visualizers interpreted the graph abstractly, divided the graph into segments, and analysed each segment separately. Low-spatial visualizers tended to see the graph as a picture, and interpreted it holistically, not dividing it into segments. Kozhevnikov et al. (2002) interpreted these findings in the context of the neurophysiological findings summarized above, postulating that the low-spatial visualizers in their study were preferentially using the ventral "what" visual pathway, while the high-spatial visualizers were preferentially using the dorsal "where" pathway. In other words, the dissociation between spatial information and

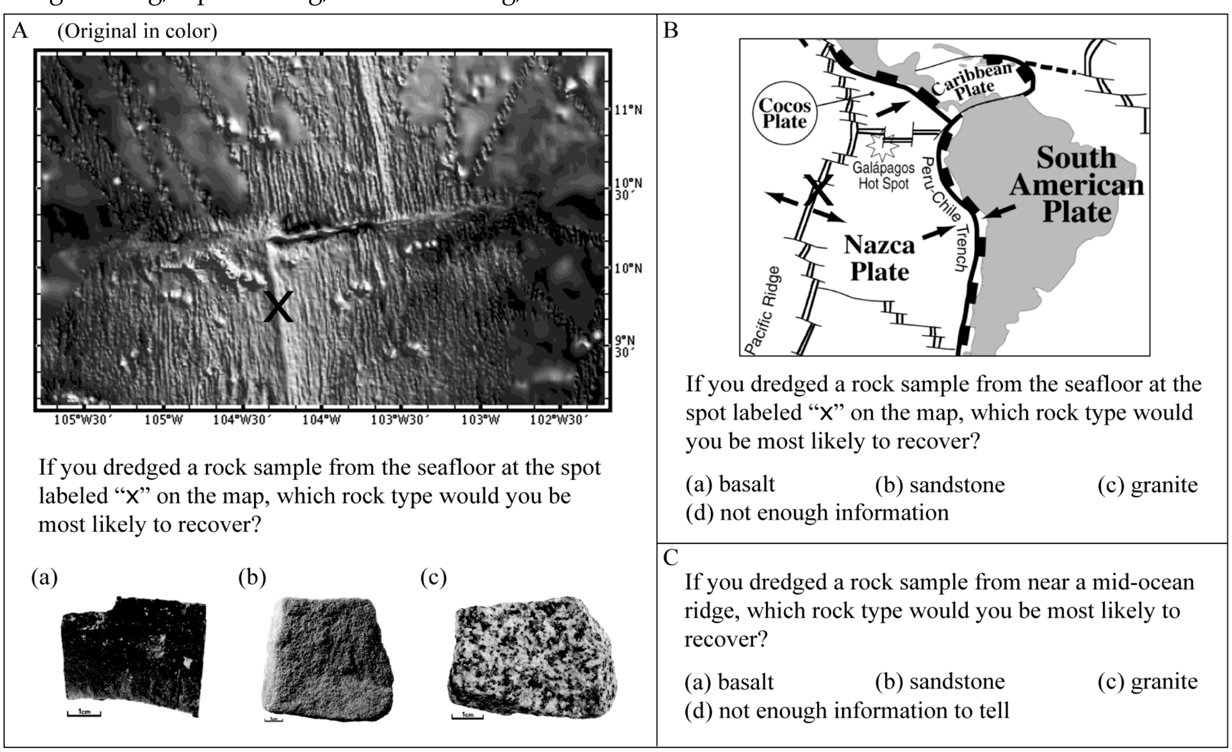

FIGURE 1. Three different variants of an assessment to follow instruction on plate tectonics and igneous rocks. (A) The most visual version (original in color) requires students to recognize the morphology of a mid-ocean ridge from shapes and colors on a shaded relief map, recall what rock type erupts in this tectonic setting, and recognize what that rock type looks like. (B) Version has the choices presented verbally, but the question is posed via a spatial representation, a map rich in symbols. (C) A completely verbal version.

object-recognition information in the brain could give rise to behavioral differences of relevance for science education.

Obviously, every normally-developing human of school age can successfully pick up a pencil from a cluttered desk, and thus can draw on both visual pathways and can coordinate the output from the two pathways to accomplish tasks of everyday life. The claim from the object/spatial visualization research is more subtle: that some individuals tend to construct, remember, and use vivid, concrete, and detailed mental images of objects, while other individuals, placed in the same circumstances and viewing the same stimuli, tend to construct, remember, and use images that represent the spatial relations between objects, the location of objects in space, and their movements.

A set of assessments is now available to distinguish among individuals with object visualizer, spatial visualizer, and verbalizer cognitive styles (Kozhevnikov et al., 2005; Blanjenkova et al., 2006a; Blanzhenkova & Kozhevnikov, 2009). Spatial visualizers score high on the paper folding task (Ekstrom et al., 1976), in which the subject is shown diagrams of a piece of paper which has been folded several times and then punched through; the task is to envision where the holes would be if the paper were then unfolded. Object visualizers are both fast and accurate at the degraded pictures task, in which the subject has to recognize a line drawing of a common object (e.g. scissors, umbrella) against a visually noisy background. The Object-Spatial Imagery Questionnaire (OSIQ) and the more recent Object-Spatial Imagery & Verbal Questionnaire (OSIVQ) ask participants to rate on a score of 1-5 their agreement with statements designed to assess object imagery, spatial imagery, and verbal preferences and abilities. These questionnaires yield separate scores for object, spatial and verbal cognitive styles.

In studies of undergraduates, strong object visualizers and strong spatial visualizers each comprised approximately 12%-16% of students (12% in Kozhevnikov et al, 2005; 16% cutoff in Blazhenkova & Kozhevnikov, 2009). The correlation between object and spatial visualization score is negative, suggesting that individuals who are strong object visualizers tend not to be strong spatial visualizers and vice versa (Blajenkova et al., 2006a; Kozhevnikov et al., 2005; Chabris et al., 2006).

RELATIONSHIP BETWEEN OBJECT/SPATIAL VISUALIZATION AND PROFESSIONS

Across a large and diverse population, men, science majors, and people with experience playing videogames scored higher on the spatial visualization scale of the OSIQ, whereas women, humanities majors, and people with experience in visual arts scored higher on the object visualization scale (Chabris et al., 2006). Kozhevnikov and colleagues examined object and spatial imagery of visual artists, architects, scientists, and humanities professionals (Kozhevnikov et al., 2005; Blajenkova et al., 2006b;

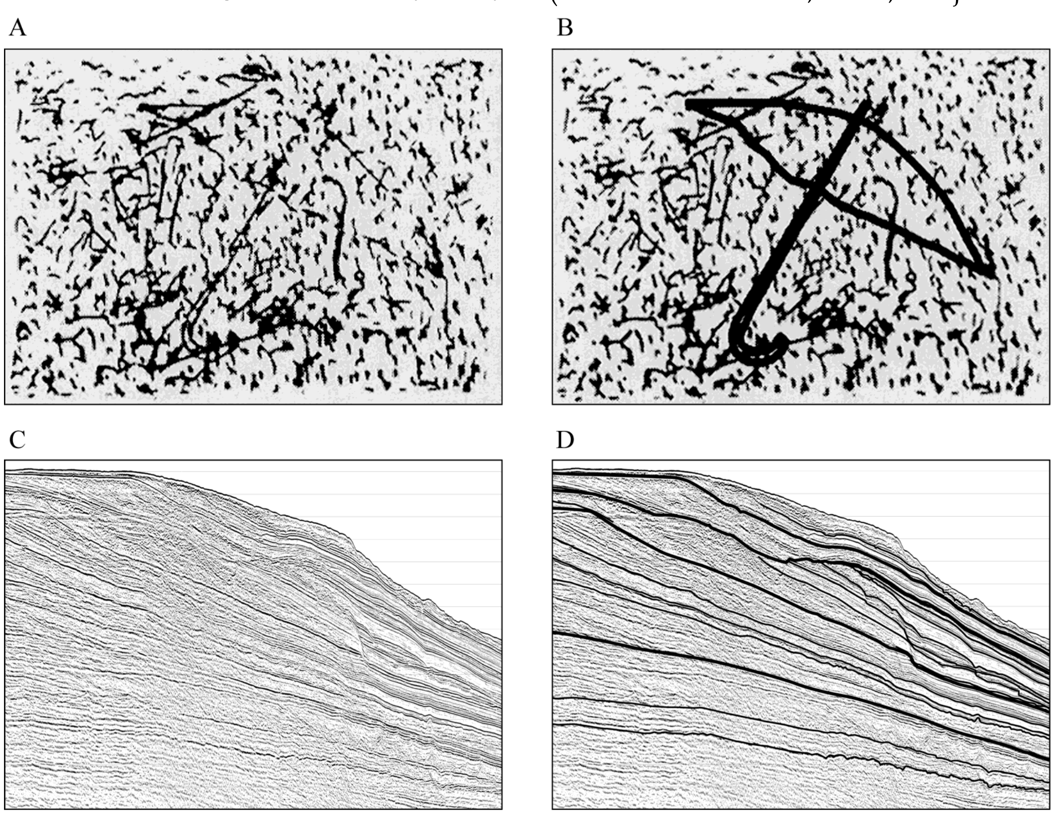

FIGURE 2: (*A & B)* Uninterpreted and interpreted item from the "Degraded Pictures Task," one of the tasks used by Kozhevnikov et al. (2005) to identify object visualizers. Participants saw image (A) on a computer screen and were instructed to type the name of the object pictured. *(C & D)* Uninterpreted and interpreted views of a continental margin seismic reflection profile. Interpretation of image data (e.g. seismic reflection, side-looking sonar, satellite remote sensing) is an example of a geoscience task that may draw on object visualization.

Blazhenkova & Kozhevnikov, 2009).The scientists included physicists and engineers, but no geoscientists. These scientists tended to perform better on tasks requiring spatial visualization, whereas visual artists tended to perform better on tasks requiring object visualization. Humanities professionals scored low on both types of imagery, but high on verbal preference and abilities. When interviewed, scientists and visual artists both reported that they used imagery in their work. But the artists reported that they preferred to use object imagery while the scientists preferred spatial imagery. The artists reported that their images were likely to come as a whole, while the scientists reported that their images were generated part-by-part.

The association between spatial thinking and success in science and engineering has been extensively documented (National Research Council, 2006). To detail only two of many studies: In a longitudinal study of 400,000 individuals, Humphreys et al. (1993) established that spatial ability (as assessed in high school by a battery of tests that included mental rotation and mental folding of 2-D figures) predicted likelihood that the individual would major in physical sciences in college and in graduate school, and would be employed in physical sciences eleven years after high school graduation. At the college level, Sorby and Baartmans (2000), have shown that poor 3-D spatial skills constitute a barrier to entry for engineering, a barrier that can be lessened through instruction.

HOW OBJECT AND SPATIAL VISUALIZATION RELATE TO GEOSCIENCE TASKS

It is unquestionably the case that certain aspects of geosciences, like other sciences, draw heavily on spatial thinking and spatial imagery. For example, the paper folding task used by Kozhevnikov et al. (2002, 2005) to identify spatial visualizers bears a strong resemblance to the structural geologists' task of imagining that that a layer of rock has been folded and faulted and then pierced by a drill hole (see Kastens and Ishikawa, 2006 their figure 10). Muehlberger and Boyer (1961) show that geology majors' performance on a spatial relations test taken at the beginning of a structural geology course correlated with course grades in structural geology and mineralogy. Kali and Orion (1996) researched high school students' difficulties in interpreting geological block diagrams, and attributed the poorest performances to students' difficulty in visualizing the inside of the 3-D volume. Piburn et al. (2002, 2005) show that paper folding performance predicts the amount learned in an introductory geoscience course, and that paper folding performance can be improved by geoscience instruction.

And yet, at the same time, there are other geoscience tasks that are tantalizing suggestive of attributes associated with object visualizers. Looking at the items on the OSIQ (Blajenkova et al., 2006a, their Table 1), the object visualizers' self-report that, "I can close my eyes and easily picture a scene that I have experienced" is a valuable skill for field geologists. The Degraded Picture Task, used by Kozhevnikov et al. (2005) to identify object visualizers, looks to my eye, like the task of interpreting seismic reflection profiles, side-looking sonar imagery, or remote sensing imagery (figure 2). In both cases, the interpreter must scan across a visually-cluttered image, and perceive a faintly visible shape that carries meaning to the interpreter.

Andris (1996) examined how students of differing cognitive style worked with a hypermedia lab on rock and mineral identification. His assessment for "visual" cognitive style required the students to picture an object in their minds, and then self-report the vividness of the

A B

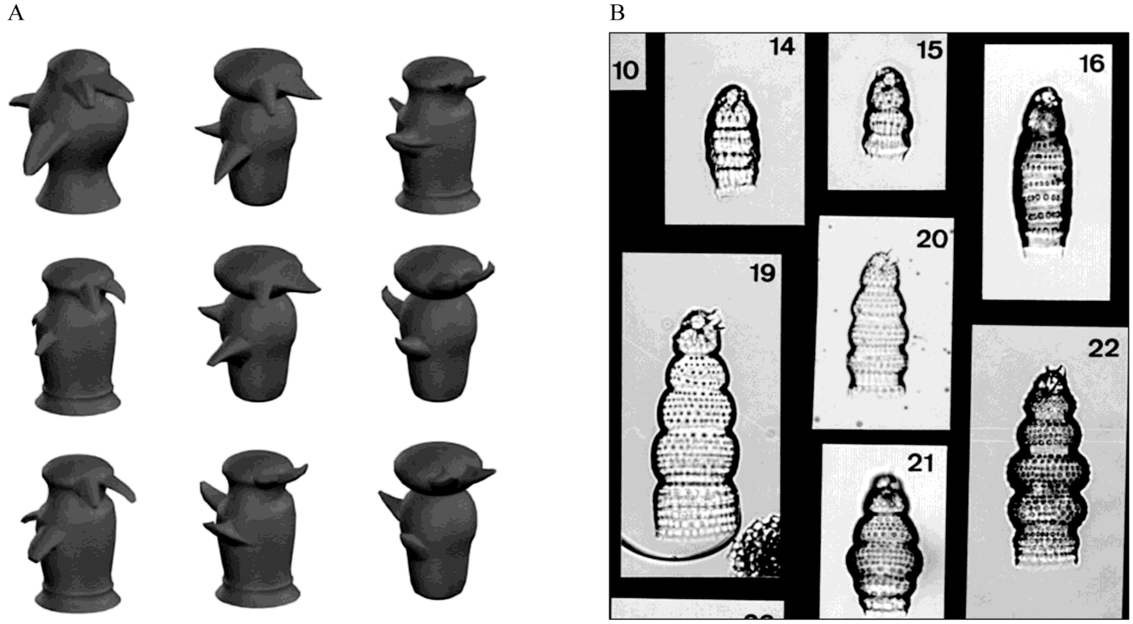

FIGURE 3. (*A*) "Greebles" were invented by Gauthier and Tarr (1997) for testing the object visualization skill of recognizing faces. Original Greebles were violet. (*B*) Photomicrographs of radiolaria (siliceous microfossils of planktonic organisms). Identifying fossils, like identifying faces or greebles, may be a task that exercises object visualization.

image; this would be a test of object visualization in our current terminology. Students with Andris's visual dominant learning style spent 39% less time in the rock and mineral simulation than their classmates, which Andris attributed to the information being in a form that was easy for them to assimilate. Rock and mineral identification, with its requirement to notice and remember visually-observed details of objects, seems likely to draw on object visualization.

Gauthier and Tarr (1997) developed a suite of fanciful 3-D rendered shapes (figure 3 left), vaguely reminiscent of closely related but not identical organisms, for use in a study about how people recognize faces. Woolley et al. (2007) later used greeble-recognition as an object visualization task in a study of collaboration between object and spatial visualizers. To my eye, recognizing greebles looks much like recognizing fossils or microfossils (figure 3 right).

Revisiting figure 1 in light of the discussion above, I interpret assessment version (A) as drawing heavily on object visualization skills, by requiring the student to recognize and ascribe causal meaning to colors, shapes and textures of landforms and rocks. Version (B) requires that the student interpret a spatial representation rich in spatial symbols. Version (C) is the completely verbal form typical of multiple choice tests, and does not require either spatial or object visualization. Given the same textbook readings, the same classroom instruction, and the same labs with rocks and maps, students with a "verbalizer" cognitive style may be more able to recall the term "basalt," while object visualizers are more able to recall the appearance of the rock sample; yet both could understand equally well the conceptual link between vulcanism and tectonic setting.

IMPLICATIONS FOR GEOSCIENCE INSTRUCTION

The clues assembled above suggest that geosciences draw heavily on both object and spatial visualization. In this sense, geoscience differs from the professions studied by Kozhevnikov et al. (2005) and Blajenkova et al. (2006b), whose practitioners tended to excel at either spatial visualization (physicists and engineers) or object visualization (visual artists). Table 1 summarizes geoscience tasks that seem likely to draw on either object visualization or spatial visualization.

Based on the correlations between cognitive style and profession cited above, it is probable that college science courses for non-science majors are disproportionately populated with object visualizers. I see reason for cautious optimism that educators can identify aspects of geoscience learning that are authentically grounded in geoscientists' professional practice, and yet are interesting to, and effective with, object visualizers, even those who have had negative experiences in prior science courses. A starting point for instructional design would be to balance tasks from the right and left columns of Table 1 in the design of both instruction and assessment. Geoscience educators have assembled a treasure trove of visually-rich instructional materials at SERC (n.d.) It's important to note that this approach need not involve dumbing down our non-science majors' curriculum into a non-rigorous "geosciences for artists" course. The object visualizers' version of figure 1 probes at least as deeply into students' mastery of geoscience as the verbalizers' version or the spatial visualizers' version.

Educators designing instruction for geoscience majors face a paradox: geosciences draw on both types of visualization, yet individuals tend to be good at one or the other, but not both. The two potential strategies would be seem to be to either look for the rare individuals who are good at both, or to develop instructional approaches that will strengthen the object visualization skills of natural spatial visualizers and vice versa. Identifying and documenting what those instructional approaches may be is fertile territory for geoscience education research.

Acknowledgements

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TABLE 1. GEOSCIENCE TASKS HYPOTHESIZED TO DRAW ON OBJECT AND SPATIAL VISUALIZATION

Spatial Visualization	Object Visualization
• Mentally unfolding or unfaulting rock layers • Use of projections (e.g., map projections, ternary diagrams, stereonets) • Envisioning 3-D structures from 1-D or 2-D data or observations (e.g. boreholes, outcrops, CTD casts in oceanography) • Envisioning trajectories (e.g. plate kinematics, atmospheric or oceanic circulation) • Remembering where an outcrop, fossil, structure, etc. was located.	• Interpreting seismic reflection profiles, side-looking sonar imagery, or remote sensing images • Identifying fossils, sedimentary structures, faults or other structures in outcrop • Identifying rocks & minerals • Classifying fossils and microfossils • Geomorphology, including identification and interpretation of landforms • Remembering what an outcrop, fossil, or geological map looked like.

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REFERENCES CITED

Andris, J. F., 1996, The relationship of indices of student navigational patterns in a hypermedia geology lab simulation to two measures of learning style, Journal of Educational Multimedia and Hypermedia, v. 5, p. 303-315.

Blajenkova, O., Kozhevnikov, M., and Motes, M. A., 2006a, Object-spatial imagery: A new self-report imagery questionnaire, Applied Cognitive Psychology, v. 20, p. 239-263.

Blajenkova, O., Kozhevnikov, M., and Motes, M. A., 2006b, Object and spatial imagery: distinctions between members of different professions, Cognitive Processes, 7 supplement, p. S20-S21.

Blazhenkova, O., and Kozhevnikov, M., 2009, The new object-spatial-verbal cognitive style model: Theory and measurement: Applied Cognitive Psychology, v. 23, p. 638-663.

Chabris, C. F., Jerde, T. E., Woolley, A. W., Gerbasi, M. D., Schuldt, J. P., Bennett, S. L., Hackman, J.R., and Kosslyn, S.M., 2006, Spatial and object visualization cognitive styles: Validation studies in 3800 individuals. The Group Brain Project Technical Report #2. Accessed April 5, 2010, from http://www.wjh.harvard.edu/~cfc/Chabris2006d.pdf.

Dubuc, B., n.d., The Brain from Top to Bottom > The Senses > Neurological > Intermediate, downloaded from http://thebrain.mcgill.ca/flash/i/i_02/i_02_cr/i_02_cr_vis/i_02_cr_vis.html.

Ekstrom, R., French, J., Harman, H., and Dermen, D., 1976, Manual for Kit of Factor Referenced Cognitive Tests, Princeton, NJ, Educational Testing Service.

Farah, M. J., Hammond, K. M., Levine, D. N., and Calvanio, R., 1988, Visual and spatial mental imagery: Dissociable systems of representations, Cognitive Psychology, v. 20, p. 439-462.

Gauthier, I., and Tarr, M. J., 1997, Becoming a "greeble" expert: Exploring mechanisms for face recognition, Vision Research, v. 37, p. 1673-1682.

Hegarty, M., & Kozhevnikov, M., 1999, Types of Visual-spatial representations and mathematical problem solving, Journal of Educational Psychology, v. 91, p. 684-689.

Humphreys, L. G., Lubinski, D., and Yao, G., 1993, Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist, Journal of Applied Psychology, v. 78, p. 250-261.

Kali, Y., and Orion, N., 1996, Spatial abilities of high-school students in the perception of geologic structures, Journal of Research in Science Teaching, v. 33, p. 369-391.

Kastens, K. A., and Ishikawa, T., 2006, Spatial thinking in the geosciences and cognitive sciences, In: Manduca, C. and Mogk, D., editors, Earth and mind: How Geoscientists Think and Learn about the Complex Earth, Geological Society of America Special Paper 413, Boulder, CO, Geological Society of America, p. 53-76.

Kozhevnikov, M., Hegarty, M., and Mayer, R. E., 2002, Revising the visual-verbalizer dimension: Evidence for two types of visualizers, Cognition and Instruction, v. 20, p. 47-77.

Kozhevnikov, M., Kossly, S., and Shephard, J., 2005, Spatial versus object visualizers: A new characterization of visual cognitive style, Memory and Cognition, v. 33, p. 710-726.

Milner, A.D. and M.A. Goodale, 1995, The Visual Brain in Action, Oxford, Oxford University Press.

Muehlberger, W. R., and Boyer, R. E., 1961, Space relations test as a measure of visualization ability, Journal of Geological Education, v. 9(2), p. 62-69.

National Research Council, 2006, Learning to Think Spatially, Washington, D.C., National Academies Press.

Piburn, M., Reynolds, S. J., Leedy, D. E., McAuliffe, C. M., Birk, J. P., and Johnson, J. K., 2002, The Hidden Earth: Visualization of Geologic Features and their Subsurface Geometry, Paper presented at the National Association for Research in Science Teaching, New Orleans, LA.

Piburn, M., S. J. Reynolds, C. McAuliffe, Leedy, D. E., Birk, J. P., and Johnson, J. K., 2005, The role of visualization in learning from computer-based images, International Journal of Science Education, v. 27, p. 513-527.

SERC, n.d., Teaching Geoscience with Visualizations: Using Images, Animations, and Models Effectively, http://serc.carleton.edu/NAGTWorkshops/visualization/index.html

Sorby, S. A., and Baartmans, B. J., 2000, The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students, Journal of Engineering Education, v. 89, p. 301-308.

Uhl, F., Goldenberg, G., Lang, W., and Lindinger, G., 1990, Cerebral correlates of imagining colours, faces and a map-II: Negative cortical DC potentials, Neuropsychologia, v. 29, p. 81-93.

Ungerleider, L., and Haxby, J. V., 1994, "What" and "where" in the human brain, Current Opinion in Neurobiology, v. 4, p. 157-165.

van de Paverd, P. J., 1995, Recent polycystine radiolaria from the Snellius-II expedition [dissertation], Center for Marine Earth Science (the Netherlands) and Paleontological Museum in Oslo (Norway), 351 pp. On the web at: http://www.radiolaria.org/plate.htm?action=show&pi_id=452&pl_id=30

Woolley, A. W., Hackman, J.R., Jerde, T.E., Chabris, C., Bennett, S.L. and Kosslyn, S.M., 2007, Using brain-based measures to compose teams: How individual capabilities and team collaboration strategies jointly shape performance, Social Neuroscience, v. 2(2), p. 96-105.

IMAGE CREDITS

Figure 1: Color version of (A) available at: http://www.ldeo.columbia.edu/~kastens/curriculum/conceptests/ Basemap of (A) created using GeoMapApp (www.geomapapp.org); basalt photo from Ichiro Kaneoka, used with permission; sandstone and granite images from Barry Marsh, School of Ocean and Earth Science, University of Southampton, UK; basemap of (B) from New York State Earth Science Reference Tables, public domain.

Figure 2: (A & B) from Kozhevnikov et al, 2005, used with permission. (C&D) from Greg Mountain, used with permission.

Figure 3: (A) from Woolley et al. (2007), used courtesy of Michael J. Tarr, Brown University, http://www.tarrlab.org; (B) from van de Paverd (1995), used with permission.